NASA Cost Estimating Initiatives

Meeting The Project Management Challenge
Joe Hamaker
NASA HQ Cost Analysis Division

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There is something fascinating about *cost estimating*.

One gets such wholesome returns of conjecture out of such a trifling investment of fact.

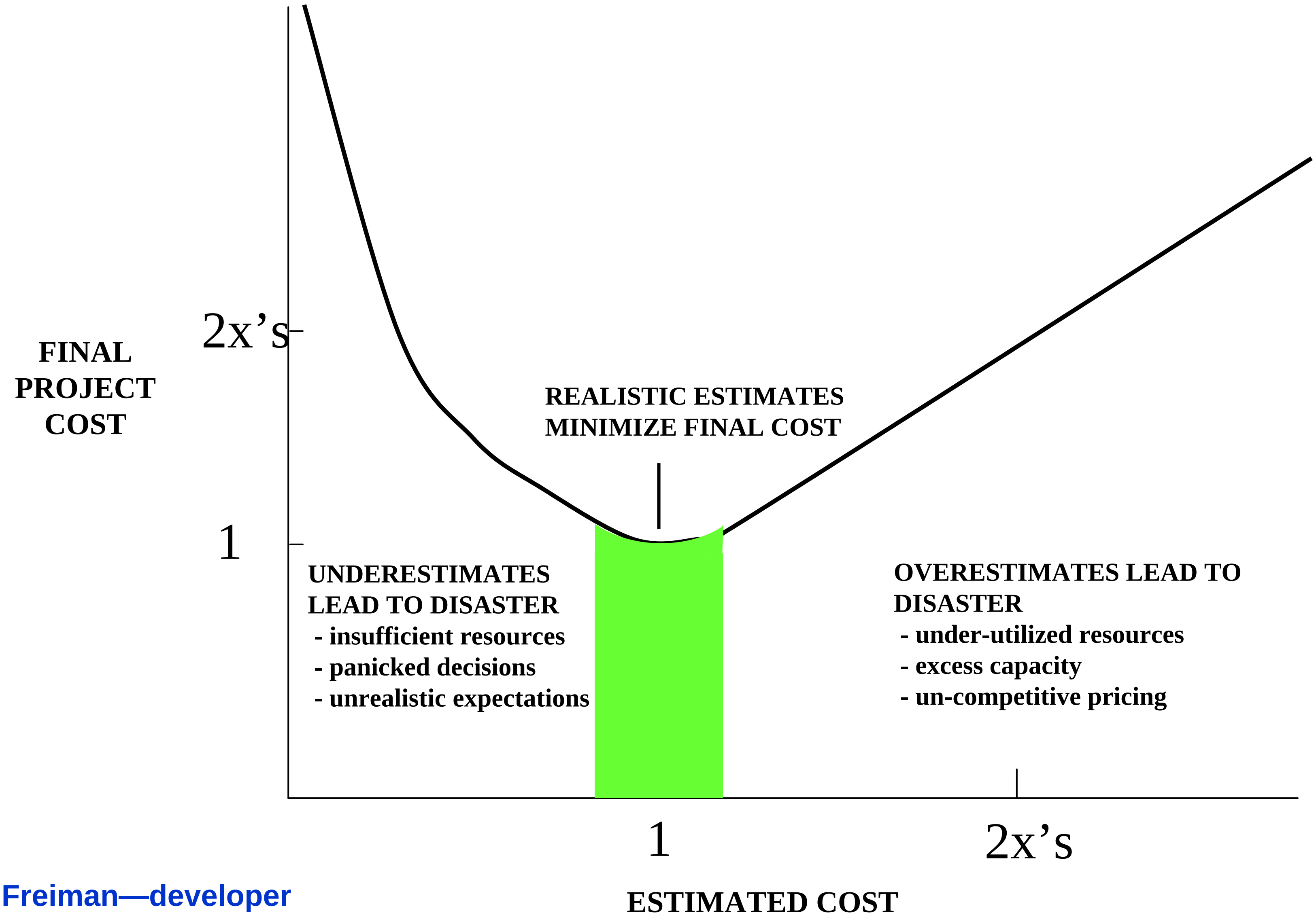
Adapted from a Mark Twain comment on *Science*

Lessons Learned (Redux)

- **Statement* from _one_ project lessons learned document:**
  – "The [xxx] Project was significantly undercosted in the proposal
  – The resulting inadequacy of budgetary reserve distorted the Project's ability to effectively solve challenging technical problems
  – Some of the best talent from [three centers] working with some of the best [contractor] talent could not overcome a significantly inadequate budget"

* identifiers deleted

The Freiman* Curve



*Frank Freiman—developer of the "RCA Price Model" (today, Price Systems, Inc.)

Cost Credibility

- **NASA history replete with cost and schedule growth problems**
  - Project cancellations due to cost and performance issues
  - Programs re-planned due to cost and schedule growth
  - Project with significant “sticker price” increases during formulation
- **Basic requirements for improvements**
  - Receptive management culture for credible cost estimating
  - Independent cross checks
    - System Management Offices (SMOs), Independent Program Assessment Office (IPAO), HQ Cost Analysis Division (Code BC)
    - Known and certain consequences for overruns
  - Improvements in people, tools and processes

Ongoing NASA Cost Estimating Initiatives

- Cost Growth Monitoring
- Cost Analysis Data Requirement (CADRe)
- One NASA Cost Estimating (ONCE) Database
- Cost Readiness Levels
- Cost risk analysis methods and best practices
- Cost Risk Feedback Continuum
- Full cost estimating methods
- NASA Inflation Index
- Cost Estimating Handbook
- NPR 7120.5C
- Cost Estimator Career Guide
- Process Based Cost Estimating
- Improved Operations Cost Modeling
- Use of COTs tools

Today's Topics

NASA Cost Growth: A Look at Recent Performance

Analytic Approach

•Compared initial and final budget estimates of development costs for 45 recent projects

- **Great Observatory missions**
  - Chandra, or Advanced X-ray Astronomical Facility (AXAF)
  - Space Infrared Telescope Facility (SIRTF)
- **Discovery missions**
  - Comet Nucleus Tour (CONTOUR)
  - Genesis
  - Lunar Prospector
  - Mars Pathfinder
  - Near Earth Asteroid Rendezvous (NEAR)
  - Stardust
- **Mars Surveyor missions**
  - Mars Climate Orbiter (MCO)
  - Mars Exploration Rovers (MER)
  - Mars Global Surveyor (MGS)
  - Mars Odyssey
- **Explorer missions**
  - Advance Composition Explorer (ACE)
  - Far Ultraviolet Spectroscopic Explorer (FUSE)
  - Galaxy Evolution Explorer (GALEX)
  - High Energy Solar Spectroscopic Imager (HESSI)
  - High Energy Transient Explorer-2 (HETE-2)
  - Imager for Magnetopause-to-Aurora Global Exploration (IMAGE)
  - Rossi X-ray Timing Explorer (XTE)
- **Other missions**
  - Cassini
  - Deep Space 1
  - Stratospheric Observatory for Infrared Astronomy (SOFIA) *(not yet flown)*
  - Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics (TIMED)
- **Earth Observing System (EOS) missions**
  - Terra
  - Aura *(not yet launched)*
  - Ice, Cloud, and Elevation Satellite (ICESat)
  - Solar Radiation and Climate Experiment (SORCE)
- **Earth System Science Pathfinder (ESSP) missions**
  - First generation ESSP (combined budgets)
    - Gravity Recovery and Climate (GRACE)
    - Vegetation Canopy Lidar (VCL)—postponed
  - Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) *(not yet launched)*
  - CloudSat *(not yet launched)*
- **Other missions**
  - Earth Observing – 1 (EO-1)
  - Tropical Rainfall Measuring Mission (TRMM)
- **Space Flight and Aeronautics Projects**
  - Alternate Turbopump
  - Multifunction Electronic Display System (MEDS)
  - Large Throat Main Combustion Chamber (LTMCC)
  - Super Lightweight Tank (SLWT)
  - Checkout and Launch Control System (CLCS)—cancelled
  - X-33—cancelled
  - X-34—cancelled
  - X-38—cancelled
  - X-43, or Hyper-X
  - Environmental Research Aircraft and Sensor Technology (ERAST)
  - Tracking and Data Relay Satellite System (TDRSS) replenishment 8, 9, & 10

Overall Statistics

- **Average growth:**
  - 36% arithmetic mean
    - This statistic is the average of percent budget growth on individual projects.
  - 45% dollar-weighted mean
    - This statistic is the average of percent budget growth on individual projects weighted by final budget amount.
    - Thus, some of the more expensive projects experienced considerable budget growth.
- **Median growth: 26%**
- **35 of 45 projects exceeded the initial budget estimate**
- **Total growth: 28%**
  - This statistic is the relative change from the total of the 45 initial budgets to the total of the 45 final budgets.

Recent NASA cost growth is about 30%.

Comparison of Cost-Growth Studies

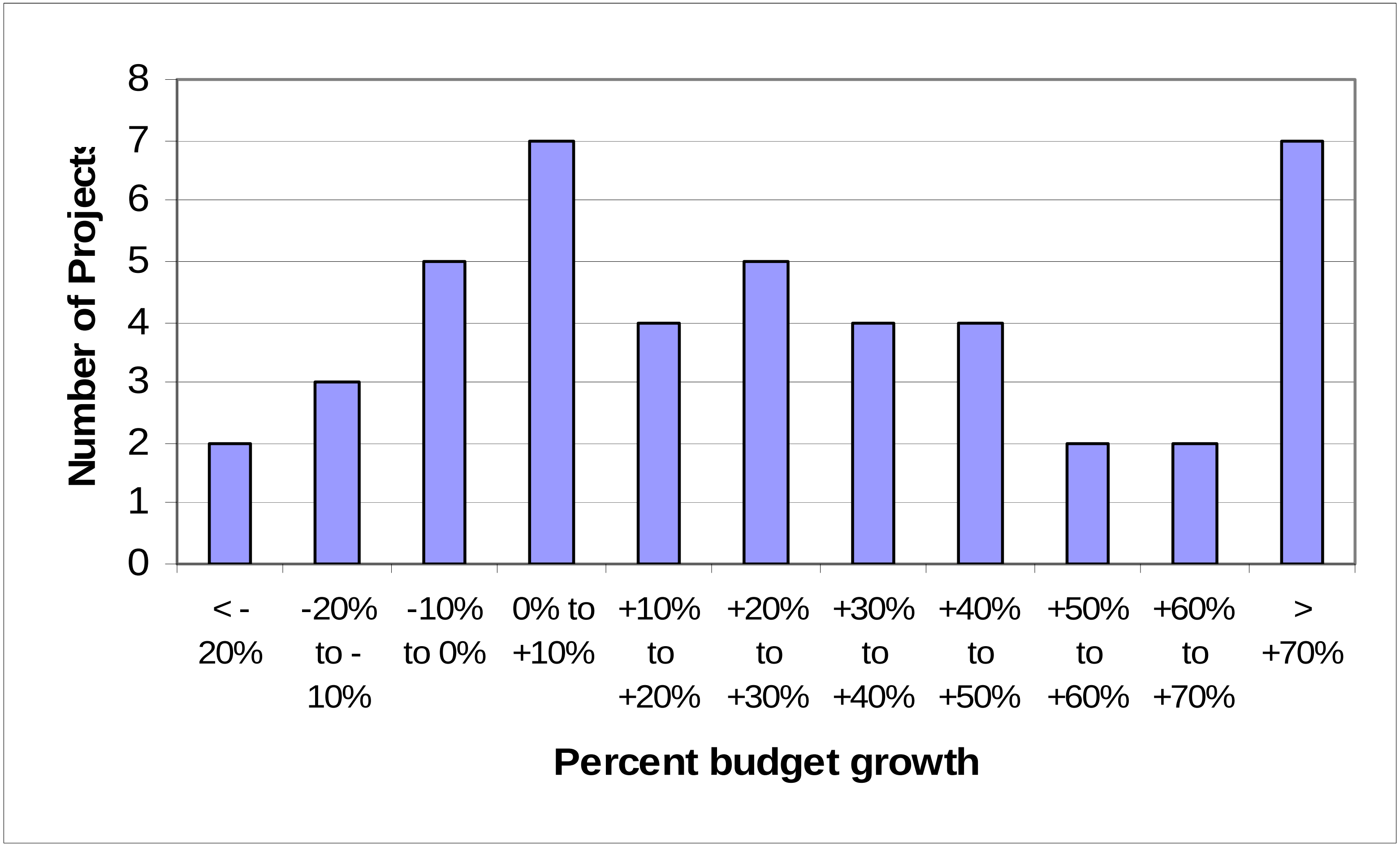
- **Average and median percent cost or budget growth of different studies, as well as the percent of projects that exceeded the initial project estimate.**

Study	Cost/Budget Growth Average	Cost/Budget Growth Median	% overruns
NASA in the 90s	36%	26%	78%
NASA in the 70s	43%	26%	75%
NASA in the 80s			
Gruhl study	61%	50%	95%
GAO study	83%	60%	89%
DoD	45%	27%	76%

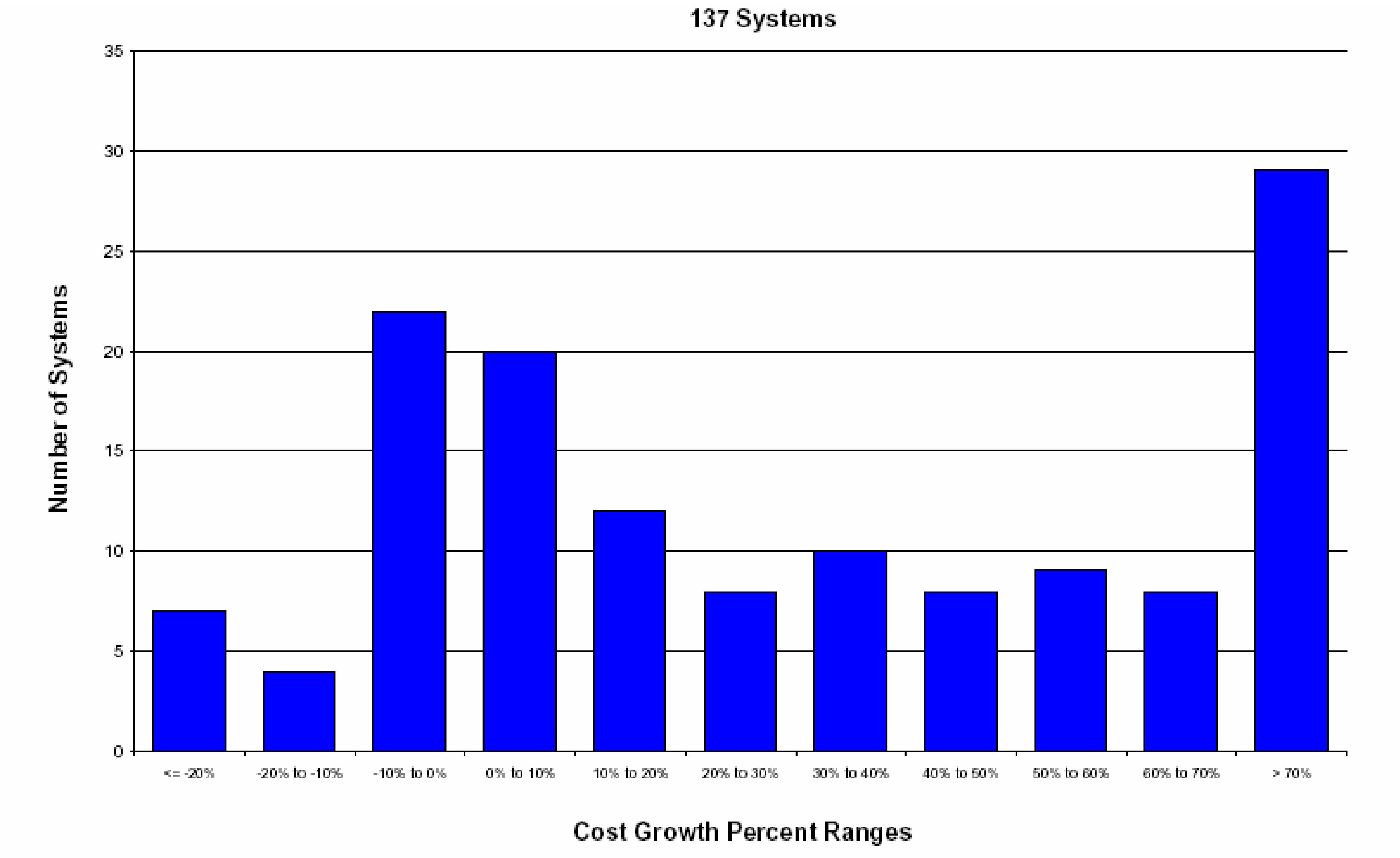
← Current Study

- **The comparison suggests that NASA cost-growth performance today is comparable to its performance in the 1970s, both of which are better than the NASA performance in the 1980s. In addition, NASA cost-growth today is comparable to the DoD history of the last thirty years.**

Distribution of Cost Growth—NASA Experience

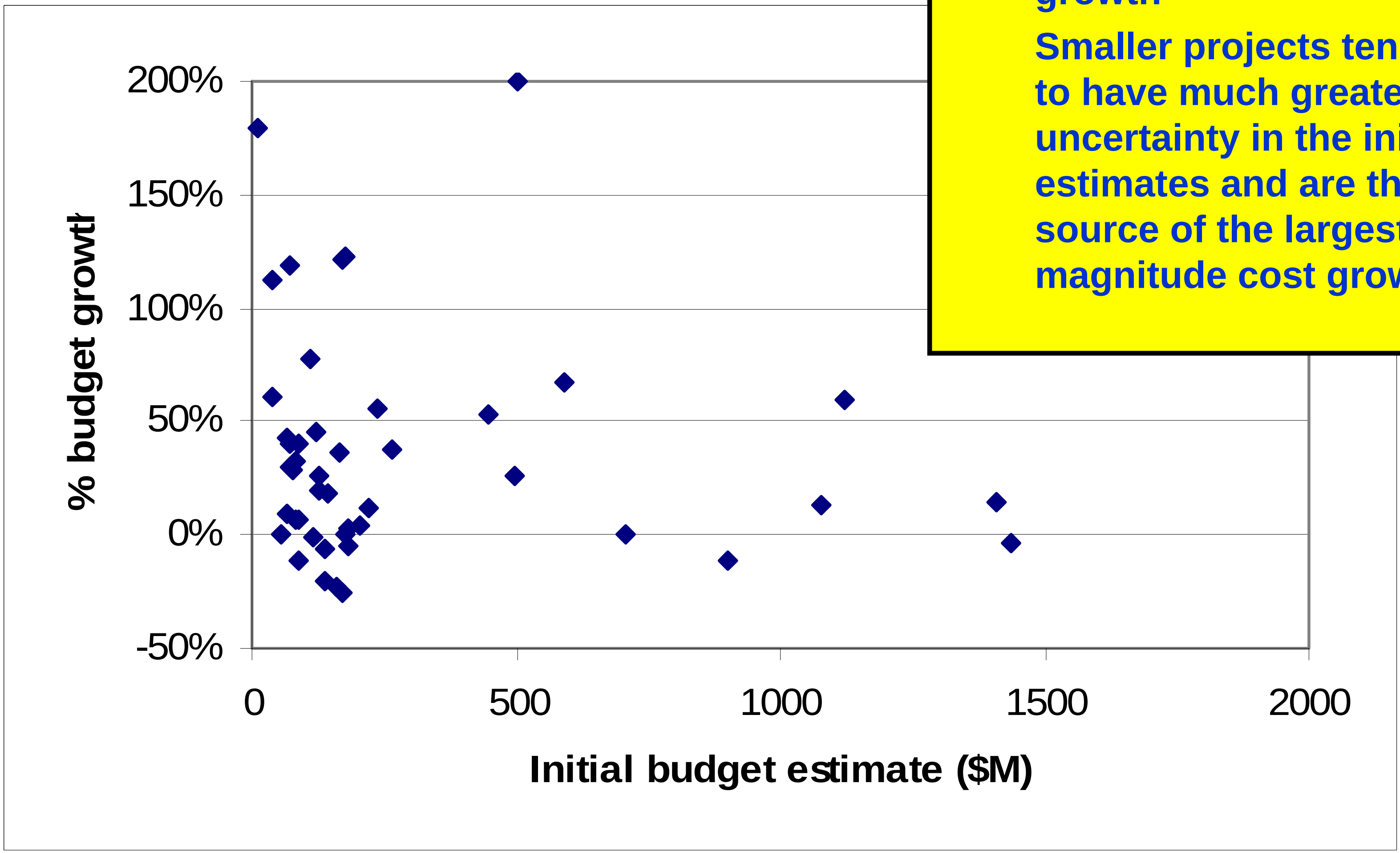


Distribution of Cost Growth--DoD RDT&E Experience

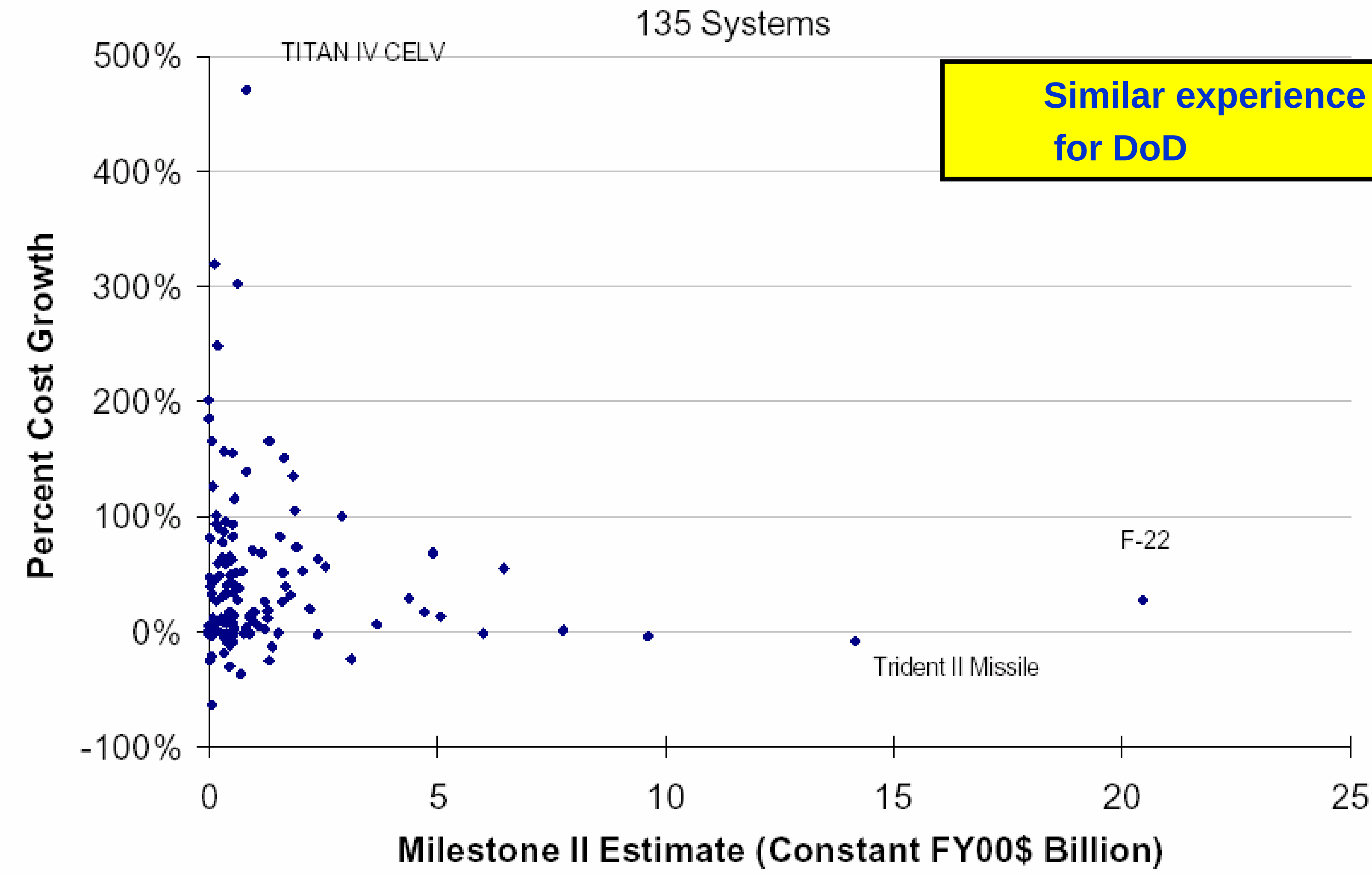


NASA Budget Growth versus Project Size

- Larger projects tend to experience less cost growth
- Smaller projects tend to have much greater uncertainty in the initial estimates and are the source of the largest magnitude cost growth

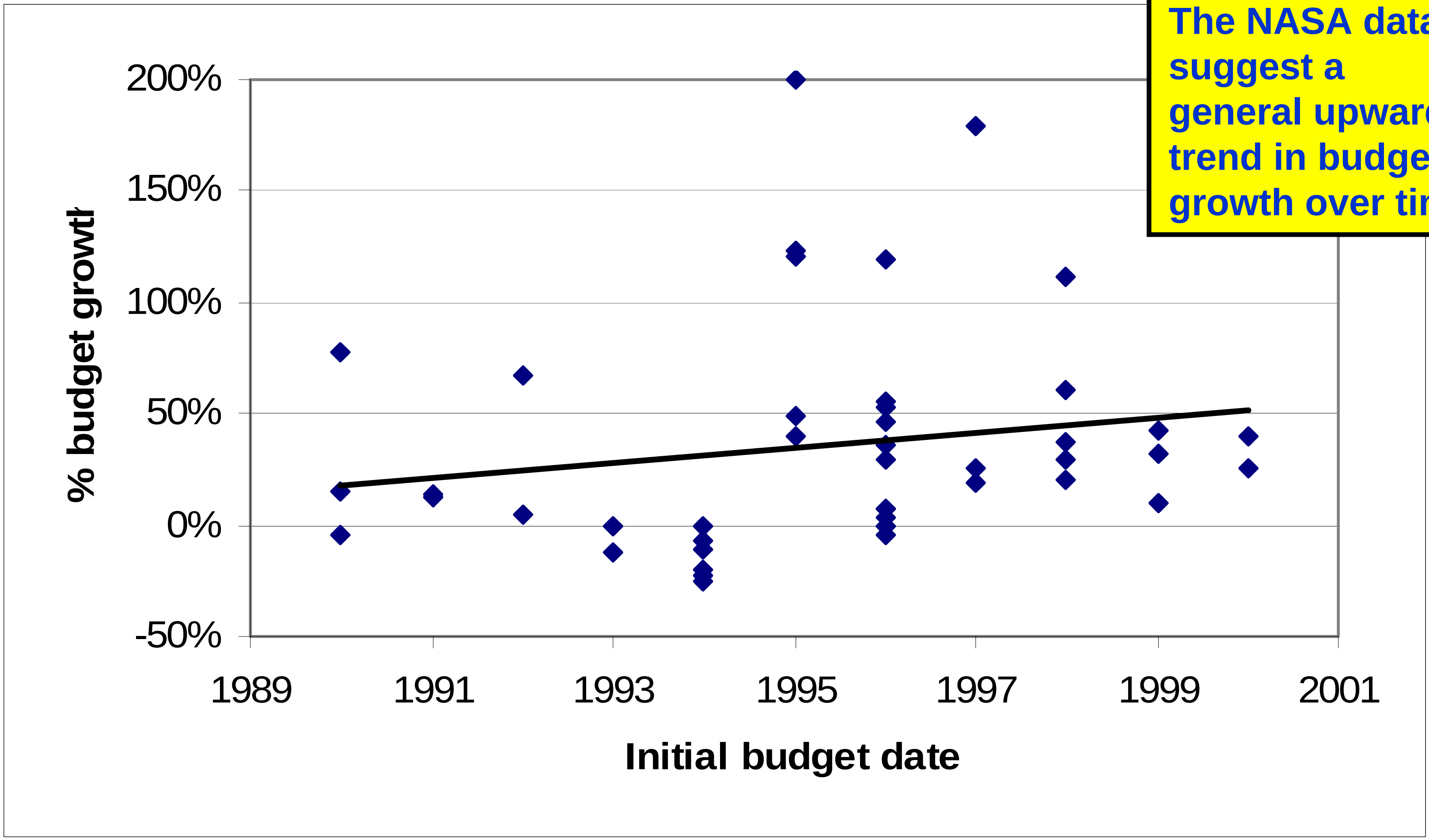


Cost Growth versus Project Size--DoD RDT&E Experience



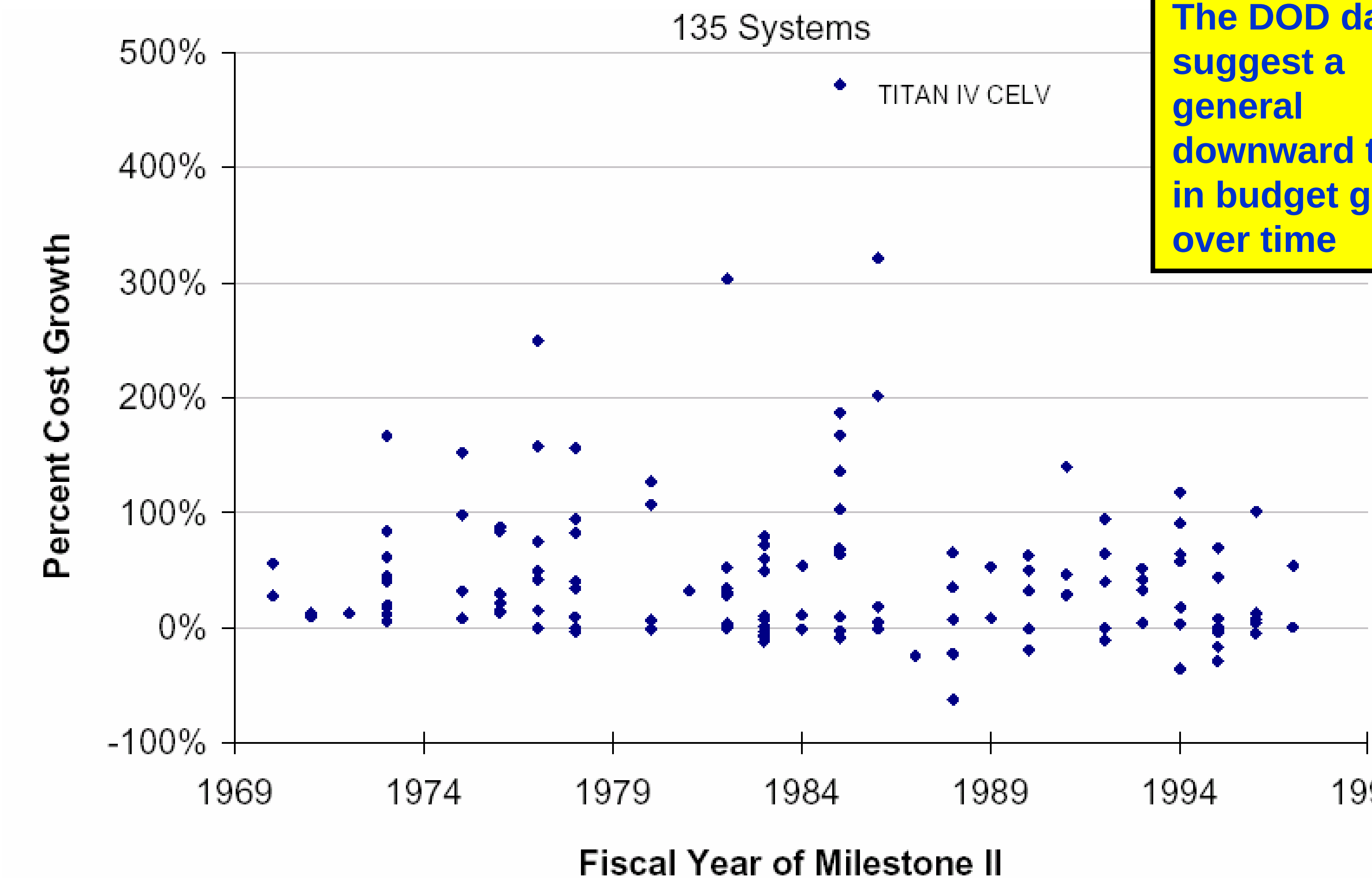
Similar experience for DoD

NASA Budget Growth versus Project Start Date



The NASA data suggest a general upward trend in budget growth over time

Cost Growth versus Project Start Date--DoD RDT&E Experience



The DOD data suggest a general downward trend in budget growth over time

Improving the Process

- **The cost-estimating process changes instituted by DoD include:**
  - Establishment of an independent cost group with a mandate to develop independent estimates prior to program approval
  - Creation of a formal document for recording key technical, schedule, and programmatic assumptions—the Cost Analysis Requirements Description (CARD)
  - Formal system for collection of contractor cost data
    - The Defense Cost and Research Center (DCARC) collects historical Major Defense Acquisition Program cost data in a joint service environment to support estimates the cost of ongoing and future programs
    - DD Form 1921 is used to obtain essential cost data from contractors for the purpose of establishing a cost database
- **In addition, DoD has introduced program-management tools for better managing to cost estimates, such as earned-value management (EVM) and cost as an independent value (CAIV)**

NASA must embrace these same process improvements.

Cost Analysis Data Requirement (CADRe)

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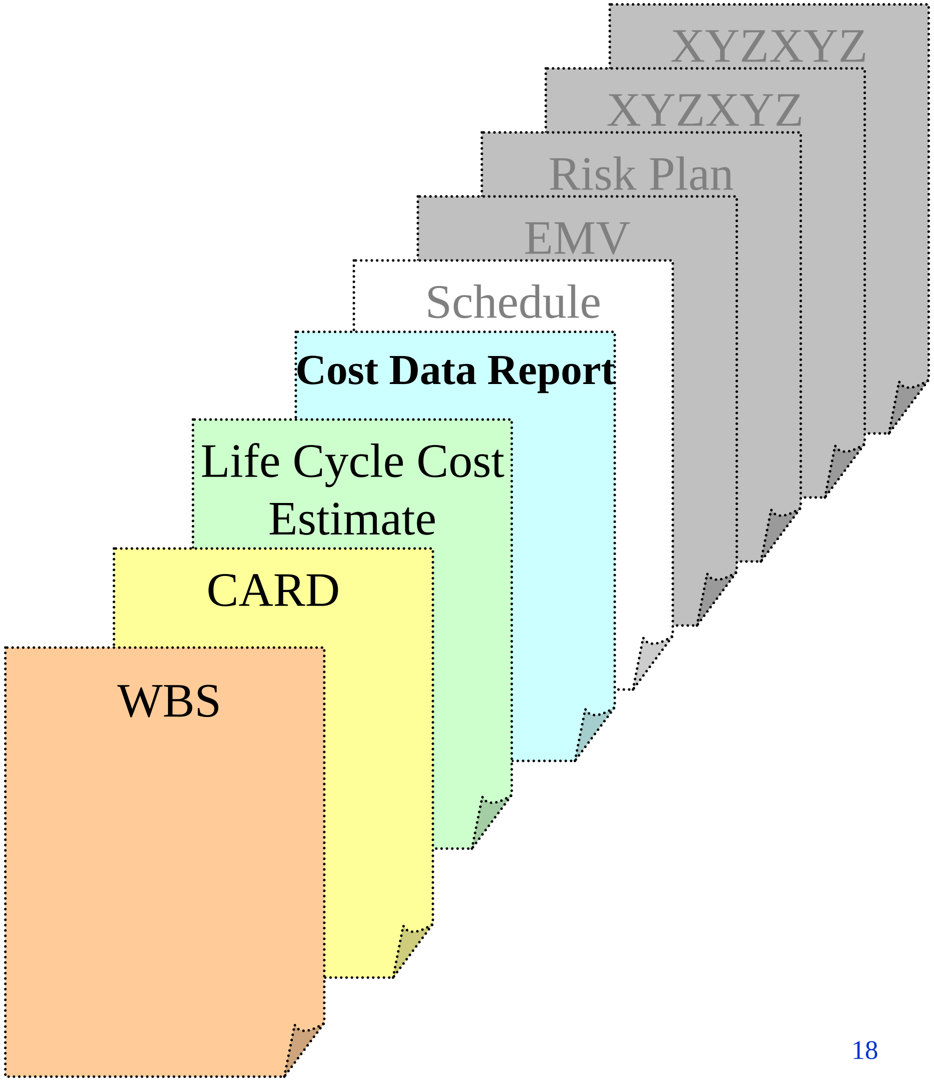
- Cost estimating touches several DRs* in a typical flight hardware development project
- There is considerable overlap in the cost data requirements
  - Especially the WBS, CARD and Life Cycle Cost, and Cost Report DRs
  - Also considerable integration needed between these DRs
- One DR can integrate many of the cost requirements
- "One stop shopping" for project cost data
- Can serve PM as a valuable management tool



*NASA DRs = DOD CDRLs

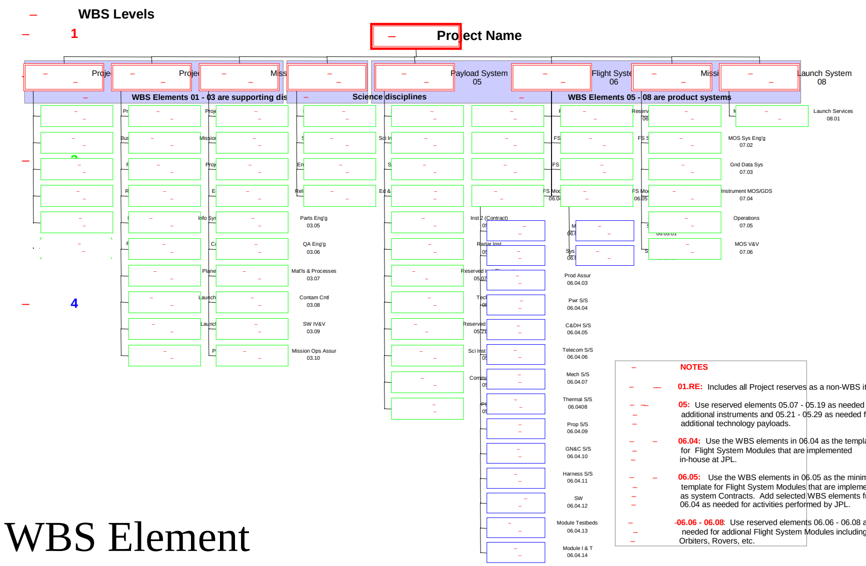
Cost Analysis Data Requirement (CADRe)

- **Most similar to a CARD but …**
  - Provides standardized WBS and WBS dictionary
  - Includes not only cost estimating inputs but cost estimates as well (as a separable appendix)
    - Contractor cost reporting
    - Project Office (full cost) cost reporting
  - Increased focus on KPPs
  - Mandatory HQ DR on Cat 1 and high risk Cat 2 flight projects
- **The CADRe must be a PM responsibility**
  - Prime contractor can build most of it
  - Cost shops at NASA Centers can support by providing definitions/interpretations of what is being asked for
    - "What is a SLOC?"
- **CADRe scope/focus**
  - Basic and applied research
  - Technology development
  - Flight projects
  - Operations
  - Functional products & services

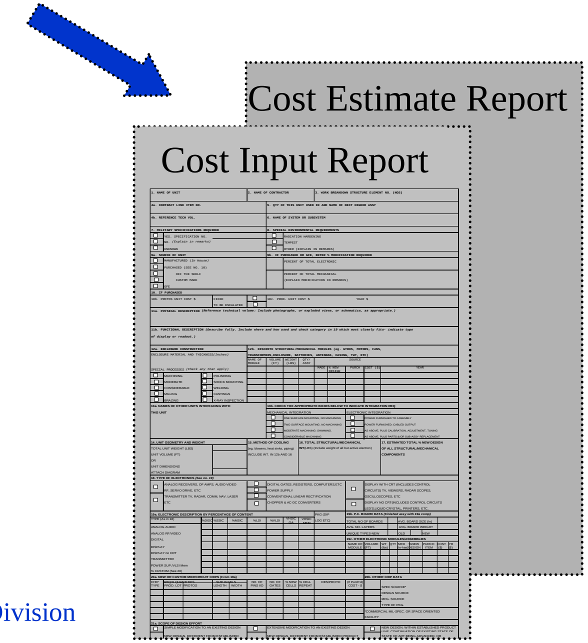
CADRe only intended as a DR on these 7120.5C categories

CADRe Contents

- **Standardized WBS structures and dictionaries to level 5 (major component level)**
  - Earth science (bus/payload)
  - Space science (bus/payload)
  - Launch systems
  - In-space transportation systems
- **Cost Input Report**
  - Data sheets for KPP cost parameters by WBS element (see next chart)
- **Cost Estimate Report**
  - Data sheets for cost estimates by WBS element
  - Contractor cost reporting
  - Project Office (full cost) cost reporting

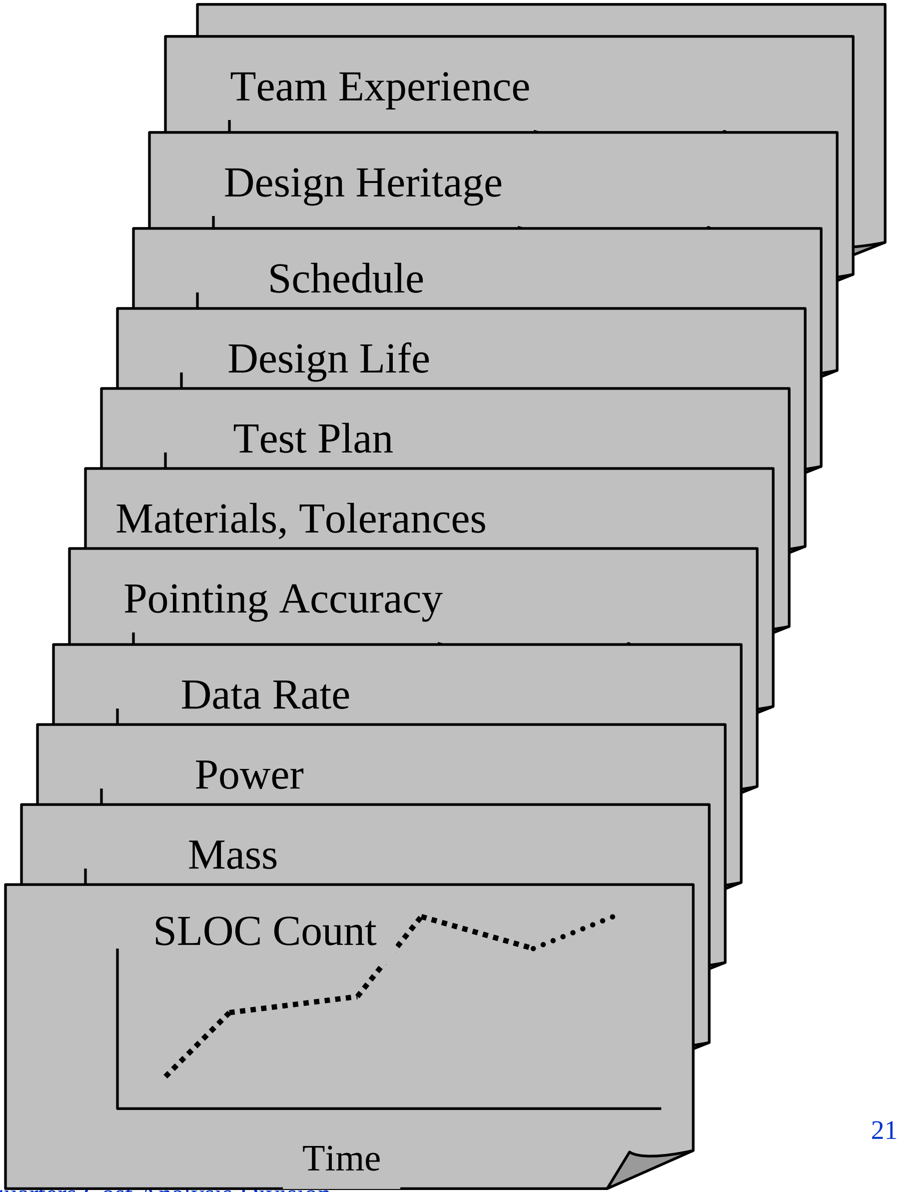


By WBS Element



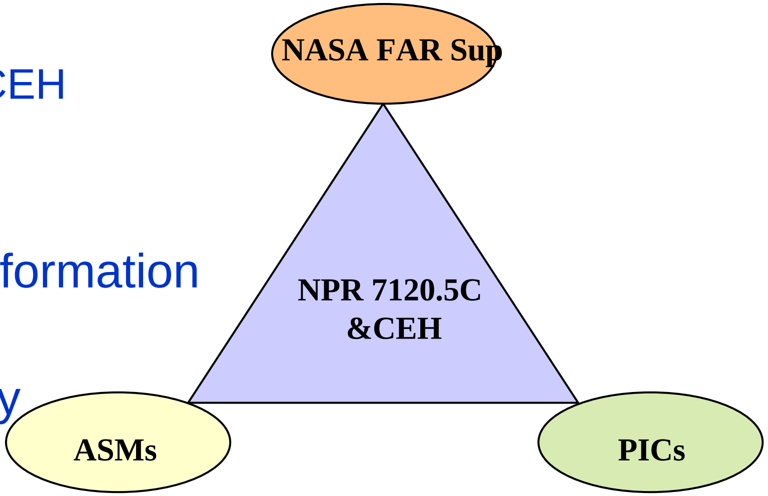
CADRe As A “Flight Data Recorder” For Management

- **The inputs for parametric cost models include a comprehensive set of KPPs as well as programmatic, schedule and management metrics that describe a project**
  - In the concise and precise language of parametric cost estimating
  - Metrics are rigorously defined by the models
- **CADRes are living documents**
  - Snapshots at least annually
  - Provides the PM with basis for updated EACs (performed by Agency parametricians)
  - Independent of contractor’s opinion
  - Provides the PM with predicted cost effects of remedial actions
  - CADRes are “encased” into the One NASA Cost Estimating Data Base
  - Automatic lessons learned and cost autopsy document



Cost Analysis Data Requirement (CADRe)

- **CADRe status**
  - To be vetted through HQ Enterprises for buy-in
- **CADRe is proposed as a RFP DR on Category I and high risk Category II flight projects**
  - Proposed for 7120.5C and the NASA Cost Estimating Handbook (CEH)
    - CADRe template downloadable from CEH website
  - Proposed for NASA FAR Supplement
  - Heads up via Code H Procurement Information Circulars (PICs)
  - To be reviewed at Acquisition Strategy Meetings (ASMs)



Once NASA Cost Engineering (ONCE) Data Base

Once NASA Cost Engineering (ONCE) Data Base

From One NASA Website

Recommendation #6

Tools and Business Practices

Increase NASA-wide cross-collaboration through common tools and business practices.

Enhance cross-Agency collaboration by putting in place standard engineering and collaborative tools and databases, processes, and knowledge-sharing structures. These tools and methods need to enhance the ability to collaborate, reduce inefficiency, and create time and resources for collaboration.

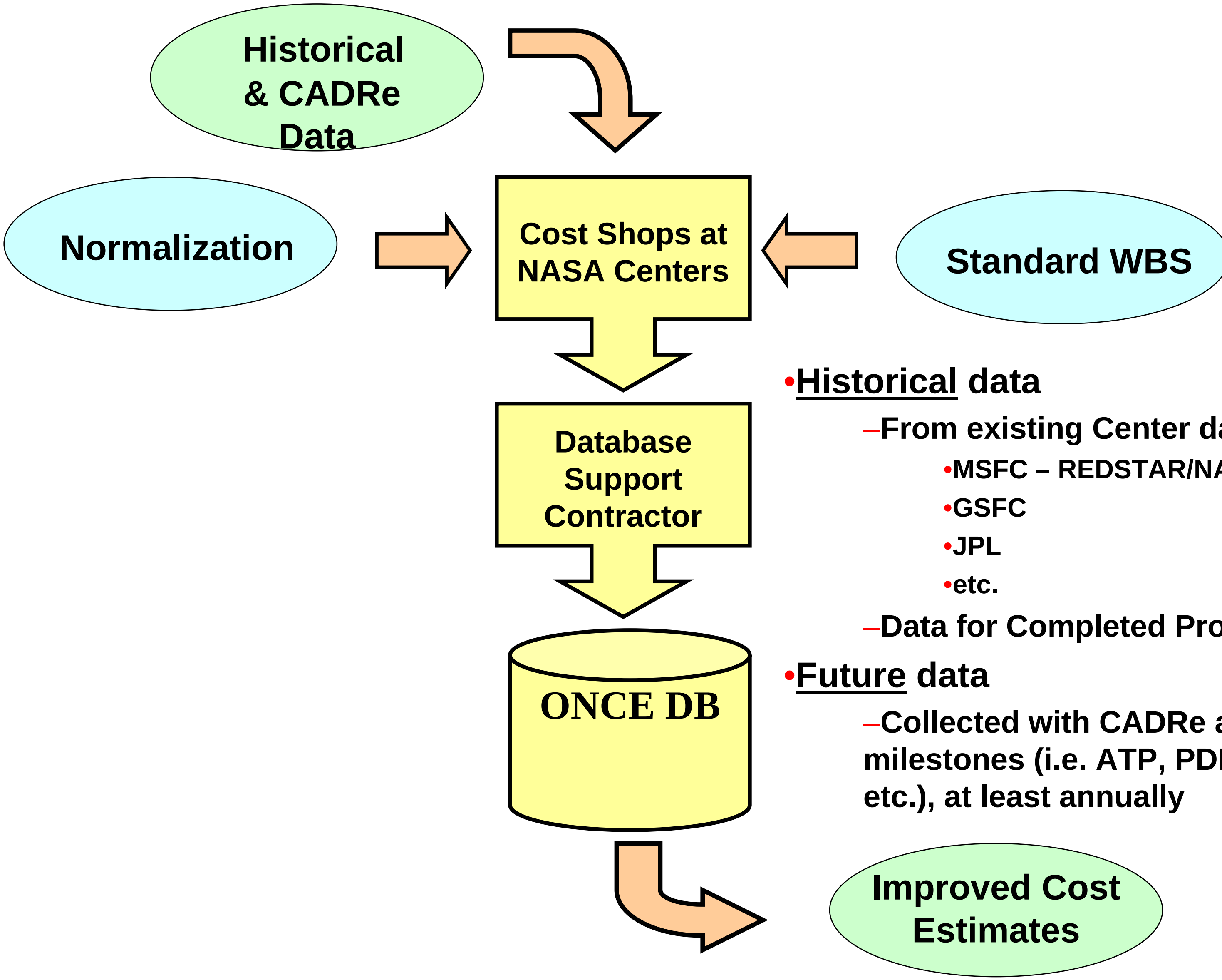
6d. Review Common Databases. *Assess the current state of databases, such as the Life Sciences Data Archive, for their ability to span multiple NASA Centers. Recommend adoption of common databases as appropriate. Develop a plan to increase awareness of databases and to provide database-specific guidelines for use.*

6f. Knowledge Management System. *Establish a formal Knowledge Management (KM) pilot project, in which KM communities of practice (COPs) can occur for a small set of engineering, research, and administrative specialized disciplines that span multiple NASA Centers—for example, thermal test engineers. Identify and train these COPs in KM principles of operation*.

One NASA Cost Engineering (ONCE) Data Base

- **A major tenet of One NASA is to share information and, where it makes sense, utilize common data bases**
- **Since 1971, NASA has had the REDSTAR Agency wide cost data base and the corresponding NAFCOM data base of normalized data**
  - Many other cost data bases exist in pockets across the Agency
  - Often estimators are unaware of or have difficulty quickly obtaining data
  - Data normalizations are not standard
- **Some Center data is undoubtedly unique to that Center's mission (e.g. presumably only KSC, MSFC and SSC are interested in rocket engines)**
  - But there remain convincing reasons to share cost data
    - "A battery is a battery" (i.e. not Center unique)
    - Will serve to standardize arbitrary WBS usage and cost normalization processes across Centers
    - Facilitates CoSTER data sharing with other USG's active in space activities
  - More data and more current data in the hands of estimators is always the direction of good

One NASA Cost Engineering (ONCE) Data Base Concept



- **Historical data**
  - From existing Center data bases
    - MSFC – REDSTAR/NAFCOM
    - GSFC
    - JPL
    - etc.
  - Data for Completed Projects
- **Future data**
  - Collected with CADRe at major milestones (i.e. ATP, PDR, CDR, FRR, etc.), at least annually

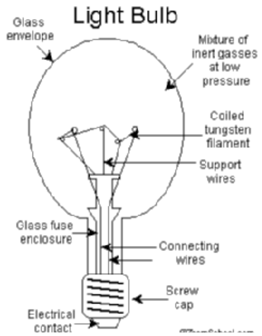
Communicating With Cost Readiness Levels (CRLs)

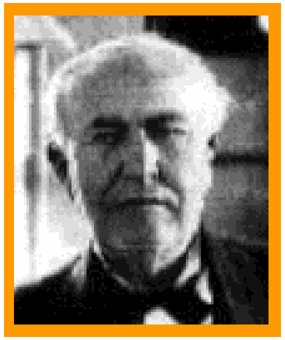
Communicating With Cost Readiness Levels (CRLs)

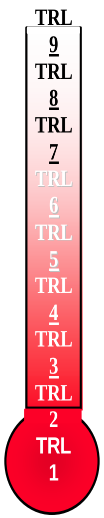
- **CRLs are patterned after the NASA Technology Readiness Level scale**
  - Like TRLs, CRLs are designed to communicate the quality of the product—its fitness for use
  - CRLs have been constructed to run the same 1 to 9 ordinal scale as TRLs
  - In the case of CRLs, it is the quality of the <u>cost product</u> itself—the estimate's fitness for use as cost information for a flight project
    - CRL 1-3:
      - <u>Not</u> fit for use for systems engineering decisions or budget commitment
    - CRL 4-5:
      - Formal cost risk probably not yet available
      - Early deterministic estimate available
      - Cost fit for conceptual systems engineering decisions and preliminary budget use
    - CRL 6-8:
      - CRL 6: "We think we are +/- 25% with 50% certainty"
      - CRL 7: "We think we are +/- 15% with 50% certainty"
      - CRL 8: "We think we are +/- 5% with 50% certainty"
      - Fit for detailed engineering decisions and firm budget commitments
    - CRL 9: End of project actual cost

Cost Readiness Levels at Low TRLs

- **If the project has critical items at less than TRL 4…**
  - This is like asking Edison in 1876 “How much longer for the light bulb, Tom?”
    - “Hard to say”, he would have said as he had you thrown out of Menlo Park
  - Note that this is not the same as asking, in 1879, once he had found a workable carbon filament, “How much will a production version of the light bulb cost to develop and produce Tom?”
    - This would have been a TRL 4 question
    - Tom’s cost estimators could have begun to model this
- **So if 1≤TRL≤3 ➔CRL=TRL$_{min}$**
- **Likewise, if requirements are not firm, then CRL < 4 (not fit for use)**







TRL9: Actual system “flight proven” thorough successful mission operations

TRL8: Actual system completed and “flight qualified” through test and demonstration

TRL7: System prototype demonstration in a space environment

TRL6: System/subsystem model or prototype demonstration in a relevant environment

TRL5: Component and/or breadboard validation in relevant environment

TRL4: Component and/or breadboard validation in laboratory environment

TRL3: Analytical and experimental critical function and/or characteristic proof-of-concept

TRL2: Technology concept and/or application formulated

TRL1: Basic principles observed and reported

Table 1: CRL Rating *Prior* to Availability of Probabilistic Risk Analysis

If Project has critical items < TRL 4, CRL = TRL_{min}

If Project requirements are not stable, CRL < 4

Otherwise, use table:

Criteria	CRL 4	CRL 5	CRL 6	CRL 7	CRL 8
Basic technical and programmatic complexity* of the "to go" work at time of estimate	Extremely complex	Very complex	Average complexity	Less than average complexity	Relatively simple
Experience and adequacy of estimating team, quality of CARD, availability of analogous data and cost tools, time allowed for estimate, independence of estimate, number of cross checks performed	Low	Fair	High	Very high	Extremely high

*Complexity considerations include include human rating, launch system requirements, planetary destination, operational vs experimental requirements, materials complexity, use of deployables, parts count, challenging thermal requirements, high data rates, electronic parts class, stabilization requirements, power generation type, propellant choice, propulsion requirements and many other factors. Programmatic complexity includes team size, team experience, schedule and many other factors.

Table 2: CRL Rating *After* Availability of Probabilistic Risk Analysis

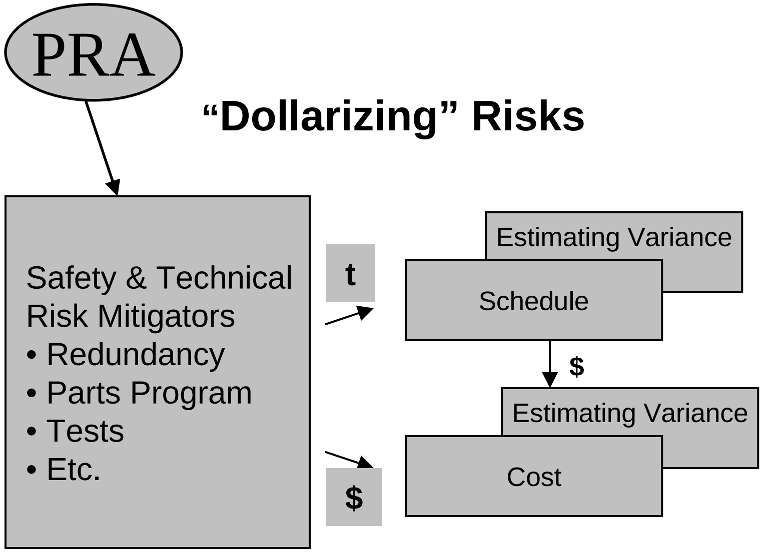
- Use inter-quartile cost range to translate to a CRL rating
  - Calculate ratio of 75th percentile cost to 25th percentile cost
  - Lookup ratio on chart to read CRL

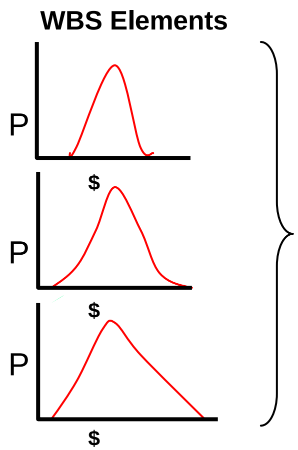
25th Percentile Cost	Median Cost	75th Percentile Cost	Lookup Ratio of 75th Percentile Cost to 25th Percentile Cost	Read CRL
100	100	100	1.00	9
95	100	105	1.11	8
85	100	115	1.35	7
75	100	125	1.67	6
65	100	135	2.08	5
55	100	145	2.64	4

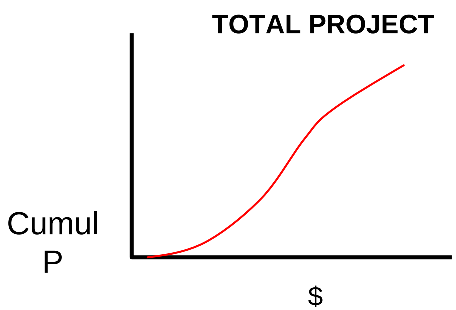
Cost Risk Analysis

Cost Risk Analysis

- **Risk Areas**
- **Safety**
- **Technical/Performance/ Engineering**
- **Schedule**
- **Cost**







Lows via modeling optimistic assumptions
Highs via modeling pessimistic assumptions

- **All cost estimates are really probability distributions**
  - **Variance narrows as project life cycle proceeds**
- **Sources of uncertainty**
  - **Uncertainties in project definition ("known unknowns")**
  - **Cost model statistical variance**
- **Cost risk analysis quantifies budget reserves necessary for acceptable level of confidence**

Cost Risk Analysis

- **Specify use of probabilistic cost risk analysis to quantify uncertainties in cost estimates**
  - Address uncertainties in technical design (especially in Phase A/B)
  - Address uncertainties in cost estimating methods (e.g. statistical variance in CERs)
  - Provide decision makers range of cost outcomes as a function of confidence levels
    - Use for reserve determinations
- **Analysis process forces the consideration of cost risks**
  - Enhances underestimating complexity of system development
  - Attaches valuation to risk reduction activities/risk mitigation plans
  - Integrates cost analysis and Probabilistic Risk Analysis
- **Generally recommend budgeting at 70% confidence levels**
  - Depending upon project scope, importance, sense of completeness of risk analysis
- **Risk dollars phased where likely be needed**
  - Problems manifest between PDR and CDR and then again during I&T
  - High leverage risk mitigation is prior to PDR

The 12 Tenets Of NASA Cost Risk Analysis

1. NASA cost-risk assessment, a subset of cost estimating, supports cost management for optimum project management;
2. NASA cost-risk assessment is based on a common set of risk and uncertainty definitions;
3. NASA cost-risk assessment is a joint activity between engineers and cost analysts;
4. NASA cost-risk assessment is composed of cost estimating relationship (CER) and technical risk assessment plus cost element correlation assessment;
5. NASA technical cost-risk assessment combines both probabilistic and discrete technical risk assessments;
6. NASA cost-risk probability distributions are justifiable and correlation levels are based on actual cost history to the maximum extent possible;
7. NASA cost-risk assessment ensures cost estimates are “likely-to-be” vice “as specified” for optimum credibility;
8. NASA cost-risk assessments account for all known variance sources and include provisions for unknown unknown sources;
9. NASA cost-risk can be an input to every cost estimate’s Cost Readiness Level (CRL);
10. NASA cost-risk integrates the quantification of cost-risk and schedule risk;
11. NASA decision makers need to know: How much money is in the estimate to cover risk events; to which WBS elements are they allocated; and, the likelihood of an overrun;
12. NASA project cost-risk data, collected as a function of government and contractor project estimates, contract negotiations and contract data requirements descriptions (DRDs), is compiled into a NASA Cost-Risk Database (NCRD).

The Cost-Risk Feedback Continuum

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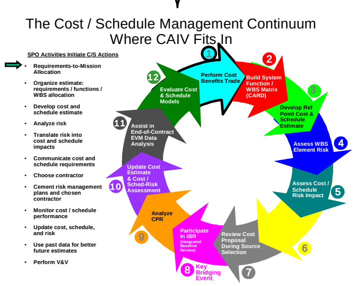
NASA Project Cycle Acquisition Phases

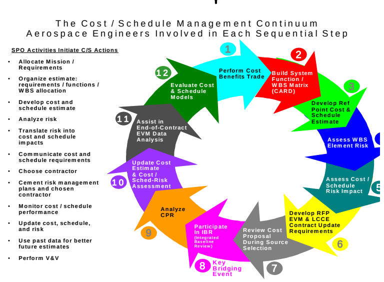
ATP
IOC

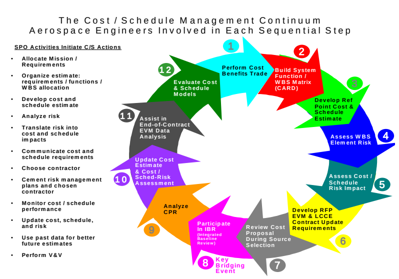
Pre-Phase A	Phase A	Phase B	Phase C/D
(Pre-Formulation)	(Formulation)		(Implementation)
Concept Exploration / Technology Development	Conceptual Design	Detailed Design	Full Scale Development

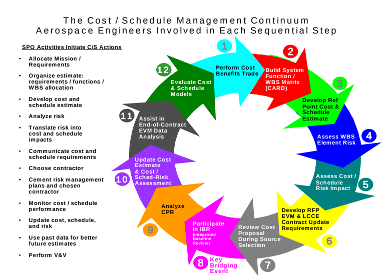
Pre-NAR
NAR
Preliminary Design Review
Critical Design Review

Preliminary CARD
Full CARD
CARD Updates as Necessary









Conclusion

- **Need better project management**
- **Need better cost estimating and management**
  - Need to recognize the interconnectedness of cost and schedule disciplines in setting up, getting, and using cost and schedule risk feedback for successful project and risk management

End